Soft Palate Disease in Horses

— Tracheal Stethoscopy as a diagnostic and evaluation tool —

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Tracheal stethoscopy as a diagnostic and evaluation tool

by RA Curtis and S Jones

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Dorsal displacement of the soft palate (DDSP) is a commonly occurring obstructive upper respiratory disease of horses. It causes a temporary respiratory airflow restriction during intense exercise resulting in loss of power and respiratory distress. It is associated with a reported gurgling sound as the horse attempts to swallow and correct the soft palate displacement. The currently preferred diagnostic procedure for evaluating DDSP is treadmill video-endoscopy. This is an invasive technique, and requires a treadmill laboratory to perform it, thereby limiting wider routine evaluation of this disease. Further, there is evidence that treadmill and field exercise with regard to this disease are not equivalent.

The aim of this project was to investigate tracheal stethoscopy as a diagnostic tool for the field evaluation of DDSP. This technique offers the potential for field measurements using non-invasive robust equipment. There is also the potential of developing an automated diagnostic algorithm. Some studies have identified spectral content of tracheal sounds as indicative of DDSP. This study focuses on time domain analysis of tracheal sounds, specifically inspiratory and expiratory periods, as an algorithmically simple approach.

The key finding of this study is that the measurement of the progression of inspiratory and expiratory periods during intense exercise is highly indicative of DDSP. These periods may be measured by tracheal stethoscopy, however external noise artefacts are significant during high intensity exercise. The use of rapidly sampled (>100Hz) respiratory temperature measurements can provide a low noise alternative for measuring respiratory periods.

This study shows that simple equipment suitable for field use in a routine training environment for the accurate detection of DDSP is possible. It demonstrates that whilst the required time-based information is contained in tracheal stethoscopy, respiratory temperature sampled at 100Hz by a datalogger is a preferred evaluation method. An early prototype of such a system is shown in the study and demonstrated to be a well-tolerated, robust system that could be easily accepted by trainers and veterinarians for the diagnosis of DDSP.

This project was jointly funded by RIRDC, Randwick Equine Centre and the Faculty of Veterinary Science at Sydney University.

This report is an addition to RIRDC’s diverse range of over 2000 research publications and it forms part of our Horse R&D program, which aims to assist in developing the Australian horse industry and enhancing its export potential.

Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation
Acknowledgments

Ethics approval was given from The Animal Ethics Committee, NSW Agriculture for the use of horses during this project. The Australian Jockey Club stewards approved all equipment used on the horses during field and treadmill exercise.

The project also acknowledges the valuable input from Honorary Associate Professor David Evans, Associate Professor Andrew Dart, Dr Jonathon Lumsden, Randwick Equine Centre, Kimberly Colletts, and Sarah Jones.

Abbreviations

DDSP   Dorsal displacement of the soft palate
FFT    Fast Fourier Transform
HSV    High speed treadmill video-endoscopy
LRC    Locomotary-Respiratory coupling
PCB    Printed circuit board
PEF    Peak expiratory flow
SNR    Signal to noise ratio
Te     Total expiratory period
Ti     Total inspiratory period
Tt     Total respiratory period
URT    Upper respiratory tract
ςE     Minute ventilation
ςT     Tidal volume
PEF    Peak expiratory flow
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Executive Summary

What the report is about

Recording respiratory sounds from the trachea or at the nostrils has been reported as effective in the diagnosis of dorsal displacement of the soft palate (DDSP). The technique is currently a research tool only and is not commercially available. This report examines tracheal stethoscopy evaluation of DDSP as a potential tool for field use in an industry-wide equine setting.

Who is the report targeted at?

Veterinarians and racehorse trainers will benefit from the results reported from this project.

Background

Dorsal displacement of the soft palate (DDSP) is a commonly occurring obstructive upper respiratory disease of horses. It causes a temporary respiratory airflow restriction during intense exercise, resulting in loss of power and respiratory distress. It is associated with a reported gurgling sound as the horse attempts to swallow and correct the soft palate displacement.

The currently preferred diagnostic procedure for evaluating DDSP is treadmill video-endoscopy. This is an invasive technique, and requires a treadmill laboratory to perform it, thereby limiting wider routine evaluation of this disease. Field video-endoscopy has also recently been introduced. There is evidence that treadmill and field exercise with regard to this disease are not equivalent.

Aims/objectives

The aim of this project was to investigate tracheal stethoscopy as a diagnostic tool for the field evaluation of DDSP. This technique offers the potential of the simple field application of non-invasive robust equipment. There is also the potential of developing an automated diagnostic algorithm for DDSP. Some studies have identified spectral content of tracheal sounds as indicative of DDSP. This study focuses on time domain analysis of tracheal sounds, specifically, changes in inspiratory and expiratory periods.

A simple field test for DDSP evaluation would be of great benefit to the equine industry.

Methods used

Tracheal sounds were recorded using a ‘neck sweat’ mounted microphone and a flash memory voice recorder. Respiratory temperature at the nares was also recorded. Data was examined using Matlab in the time and frequency domains, comparing normal horses with a DDSP horse.

Results/key findings

The key findings of this study are that the measurement of the progression of inspiratory and expiratory periods during intense exercise is highly indicative of DDSP. These periods may be measured by tracheal stethoscopy, however, external noise would significantly add to the complexity of automated diagnostic software. The use of rapidly sampled (>100 Hz) respiratory temperature measurements can provide a low-noise alternative for measuring respiratory periods.

This study shows that simple equipment, suitable for field use in a routine training environment, can be used for the accurate detection of DDSP. It demonstrates that whilst the required time-based information is contained in tracheal stethoscopy, respiratory temperature sampled measured at 100 Hz by a datalogger is a preferred evaluation method. An early prototype of such a system is shown in the
study and demonstrated to be a well-tolerated, robust system that could be easily accepted by trainers and veterinarians for the diagnosis of DDSP.

**Implications for relevant stakeholders**

The study demonstrates that potential alternative diagnostic techniques for the field evaluation of DDSP are possible. The development of equipment described in this study would allow DDSP evaluation to form part of a regular training routine without disruption or freighting of horses to treadmill facilities. Importantly, it allows testing to be done under racing-encountered conditions.

**Recommendations**

Further data collection would be required on a larger population to better characterise the condition. This larger dataset could aide in setting the diagnostic conditions such that automated software-based diagnosis could be realised.
Upper respiratory tract (URT) disorders have been identified in 6.3% of the general racehorse population and in 32% of horses examined for poor performance (Brown et al. 2005). Poor performance from URT disorders results in a reduction in racing performance potential, and may cause substantial economic losses. For this reason, the aetiology, diagnosis and treatment of URT disorders are of great importance to an industry where performance is imperative.

Dorsal displacement of the soft palate (DDSP) has been observed in highly significant proportions of horses diagnosed with a URT disorder during high intensity exercise (78%, Lane et al. 2006b; 39%, Tan et al. 2005). It is estimated to be one of the most common, performance-limiting obstructive conditions of the upper respiratory tract of racehorses (prevalence of 22–32%, Dart et al. 2001).

For normal breathing, the caudal edge of the soft palate is tucked under the epiglottis, forming a seal between the oral and nasal cavities (Lane 1993). This allows air to freely pass from the nares, through the larynx to the trachea. During deglutition, the epiglottis is moved to form a seal across the rima glottis. The caudal edge of the soft palate then moves to seal with the roof of the nasopharynx. This valve action allows food and saliva to pass between the oral cavity and the oesophagus, sealing the lungs from food and saliva.

During an episode of DDSP the caudal free border of the soft palate is unsupported and may be drawn dorsally into the rima glottis during expiration (Morris and Seeherman 1990), temporarily obstructing airflow and causing partial asphyxia, especially during expiration (Couroucé-Malblanc et al. 2002; Franklin et al. 2006; Roethlisberger-Holm 1995). This condition only occurs during high intensity exercise.

During high intensity exercise, deglutition is observed in normal race-fit horses (Curtis et al. 2007) and must be of a duration to synchronise with gait due to locomotory-respiratory coupling (LRC); (Lane 1993). DDSP has been described as “delayed relocation of the soft palate post deglutition” (Attenburrow 1996). Characteristically, in field response to DDSP, the horse slows down and swallows to replace the palate into a sub-epiglottic position. The horse then rapidly recovers and the abnormal respiratory sound ceases (Roethlisberger-Holm 1995), and LRC is re-established.

DDSP has been associated with the production of abnormal respiratory sound, referred to as ‘fluttering’ or ‘gurgling’. Vibrations of the caudal edge of the palate during expiration are believed to be the primary source of the abnormal respiratory sounds associated with DDSP (Anderson et al. 1995; Dersken 2001; Morris and Seeherman 1990). It has been suggested, however that up to 30% of horses that experience DDSP, typified by a sudden loss of power and a fast recovery, do not exhibit abnormal audible respiratory sounds (Ahern 1999; Hubert and Brown 2008; Martin et al. 2000).

Despite being first reported by Quinlan in 1949 (Ducharme 2001), DDSP is still possibly the least understood of the equine URT disorders, as the pathogenesis of this condition has not been clearly defined (Holcombe et al. 1999). The aetiology of DDSP appears to be multi-factorial, involving a combination of intrinsic and extrinsic factors. As DDSP episodes are transitory, and observations must be made during high intensity exercise, identifying the condition can be diagnostically challenging.
Currently reported methods of DDSP detection

Treadmill endoscopy

High speed treadmill video-endoscopy (HSV) provides a controlled method of high intensity exercise provocation with the ability to visually observe and replay soft palate movements.

Disadvantages of HSV include the inability of horses to reach race speeds on treadmills; consequently not all horses will exhibit signs of DDSP during treadmill exercise (Geor et al. 2004; Roethlisberger-Holm 1995; Villella 2010). HSV may also not yield an accurate diagnosis because of the artificial conditions under which the horse is exercised (DerkSEN 2003). Anecdotally, some horses that are reported by riders and trainers as having ‘tied up’ during field exercise cannot be provoked during clinical HSV to DDSP. The specialist facilities that treadmill video-endoscopy requires preclude this as a low-cost diagnostic technique that might be broadly applied to the equine industry.

Further, treadmill-exercised horses do not require, and are not generally exercised with a bit. It has been suggested (Cook 2003), that the use of a bit may indeed exacerbate a tendency for soft palate displacement. There are currently no published reported results comparing DDSP observations during HSV with and without a bit.

Stethoscopy

Stethoscopy\(^1\) is a potential alternative diagnostic tool for the non-invasive evaluation of respiratory abnormalities of an exercising horse, both on the treadmill and in the field. The apparatus consists of either a microphone positioned close to the nares, or a contact stethoscope-style microphone positioned over the trachea. The resultant signals may either be recorded on the horse using a solid state recorder or telemetered to a recorder for further analysis.

Attenburrow (1996) has previously described sound recorded from a tracheal microphone during exercise in normal, recurrent laryngeal neuropathy (RLN) and DDSP Thoroughbred horse cases during field exercise. To distinguish inspiratory from expiratory sounds, Attenburrow used a footfall marker switch. DDSP data was presented in the time domain and the stride rate was derived from the respiratory time domain envelopes. Attenburrow reported that DDSP episodes were significantly related to a sudden decrease in stride frequency.

Frequency domain analysis of respiratory sounds has been reported with a significant spectral peak of 20–90 Hz for DDSP (DerkSEN et al. 2001). This spectral energy has been confirmed as emanating from the soft palate by cadaveric studies (FrankLIN et al. 2004).

Flow and respiratory temperature

The effect of DDSP on respiratory air flow has been described using ultrasonic flow meters during treadmill exercise with simultaneous endoscopy (FrankLIN et al. 2002). During the DDSP period this study found a significant decrease in minute ventilation (\(\zeta_E\), tidal volume (\(\zeta_T\), and peak expiratory flow (PEF). During DDSP the expiratory period (\(T_e\)), significantly increased and the inspiratory period (\(T_i\)) proportionately reduced, maintaining the total respiratory period (\(T_t\)) equal to the pre-DDSP period. This indicates that on a treadmill, locomotary-respiratory coupling was maintained during the DDSP episode.

\(^1\) Stethoscopy is also called Sonography by some authors; stethoscopy has been preferred in this article as dermal contact microphones were used.
A comparison of the results from Franklin et al. (2002) and Attenburrow (1996) indicates that in field studies LRC was affected by DDSP, whereas on a treadmill it was not. This suggests that the motion imperative of a treadmill may affect the outcome of a DDSP test.

To aid in the signal analysis of recorded breath sounds, Attenburrow (1996) noted the necessity to add an additional method for distinguishing inspiration from expiration. This was achieved by recording the operation of a manual marker switch when observing stride. In flow measurements using the Quadflow pneumotach (Curtis et al. 2004), a fine thermocouple probe was used to measure respiratory temperature. This proved to be a reliable method of monitoring the respiratory cycle when mounted in a mask, and gave good correlation to respiratory air flow (Figure 1). As shown, a similar result was obtained using a rapid response sub-miniature thermistor.

Note: Upper trace – flow measured by Quadflow pneumotach; Lower trace – respiratory temperature measured by ultra-fine thermocouple

Figure 1  Deglutition during treadmill exercise at 9 m/s.

Aims of this study

The aim of the present study was to evaluate the use of tracheal stethoscopy as a simple, low-cost and non-invasive method of detecting DDSP in a field situation suitable for implementation in training and racing centres.

This study investigated concurrent stethoscope and thermistor recordings during both high speed field and treadmill exercise in Standardbred and Thoroughbred racehorses. Horses with no prior history of ‘gurgling’ were compared to those which had displayed clinical signs of DDSP during high speed field and treadmill exercise.

The study also examined the resultant recordings for data quality necessary for use as the basis of a routine diagnostic test.
Methodology

Horses

Six horses (two Standardbreds and four Thoroughbreds) were classified by reported exercise tolerance (Table 1). Horses were ranked on a scale of 1–5 to determine their current racing performance. A rank of 1 indicated poor general racing performance, or incidence of sudden onset of exercise intolerance or production of respiratory noise during exercise. A rank of 5 was used for a horse with no prior history of exercise intolerance or abnormal respiratory sounds during exercise.

Table 1 Horses evaluated during high speed exercise.

<table>
<thead>
<tr>
<th>Horse</th>
<th>Breed</th>
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<th>Age</th>
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<tr>
<td>Normal URT function</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
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</tr>
<tr>
<td>F</td>
<td>TB</td>
<td>G</td>
<td>6</td>
<td>-</td>
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</table>


Recording respiratory sounds – stethoscopy

A contact throat microphone, positioned on the skin overlying the trachea, was used to detect respiratory sounds. These sounds were recorded using a digital voice recorder (Olympus WS-300M), recording in WMA² format at a sampling rate of 44100 Hz. The left channel recorded breath temperature, and the right channel recorded tracheal sound. The recorder featured 256 MB of internal flash memory, was powered by AAA batteries and included a USB output, so that data could be downloaded onto a computer for processing.

The recorder and microphone were attached to a neoprene ‘neck sweat’ style collar fastened by Velcro around the neck of the horse. This equipment could be very quickly applied, and ensured correct microphone placement. This system was well tolerated by all horses to which it was applied. The recorder was started just prior to the collar being attached to the horse. Respiratory recordings were taken continuously for the duration of the exercise.

Thermistor

An ultra-fast response miniature thermistor (Part 10K3MCD1, Betatherm, Galway, Ireland) was attached to each horse during high speed exercise to detect the changes in temperature of the respiratory gas and define the time of inspiration and expiration periods. The thermistor resistance controlled the modulation frequency of an oscillator to allow low frequency signals to be recorded on

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² WMA Windows Media Audio
the voice recorder. At 20°C the frequency was set to approximately 2.4 kHz. The thermistor tip (0.38 mm wide and 2 mm long) was positioned in the direct path of respiratory flow at the left nostril.

For all horses except Horse F, the thermistor was bound to an open, soft plastic mesh (1cm squares) that wrapped around the front of the nose. The mesh was secured to the bridle (Figure 2). For Horse F the thermistor was held in front of the nostril by a thin piece of flexible wire supported by the bridle nose band.

Figure 2 The stethoscopy device secured around the neck of the horse and the position of the mesh mask holding the thermistor in place.

Exercise protocol

Field exercise

Horses A and B were exercised in the field on a 740 m track. The exercise regime consisted of a five minute warm up at a walk, 2220 m trot to pace, 740 m walk. This was followed by the fast work that consisted of 3700 m pacing. Halves were completed in mile rates of 131 s, 126 s and 122 s each. To warm down, the horses were walked for 1480 m.

Treadmill exercise

Horses C, D, E and F participated in high speed treadmill exercise. The treadmill was set to 5° inclination and the speed protocol used was 2 minutes at 1.8 m/s, 4 minutes at 3.5 m/s, 2 minutes at 7 m/s. This was followed by fast work for 3 minutes at 10 m/s unless the horse was unable to maintain this due to exhaustion, respiratory distress, or if DDSP was detected (Horse F has confirmed DDSP). A cool down period of at least 3 minutes at 1.8 m/s followed.

Endoscopy

All horses were endoscoped for normal URT function at rest. Horses C, D, E and F underwent high speed treadmill video endoscopic examination. This requires the tip of the endoscope to be passed through the left nostril and positioned in the pharynx so that the soft palette, epiglottic apex and rima glottis are visible (Dart et al. 2001). Video-endoscope recordings were used to confirm that the horse had suffered from an episode of DDSP.
Data analysis

The recorded WMA data files were transferred to a computer, converted to WAV format and sampled at 22050 Hz in 16 bit for analysis. Data was viewed and selected using the sound editor software Cool Edit Pro 1.1 (Syntrillium). The data may be viewed in either the time or frequency domains with this software.

Five second periods of high speed exercise test were extracted at 15 second intervals. These extracts were then transferred into Matlab (Mathworks) for further data analysis.

Signal processing

Signal processing software was written using Matlab. The respiratory temperature was software demodulated. Respiratory sound in the time and frequency domains was plotted in conjunction with the respiratory temperature graph to confirm respiratory phases. The start of inspiration was identified by a decrease in respiratory temperature and the beginning of expiration was identified by an increase in respiratory temperature.

The respiratory sound envelope was calculated in an attempt to de-noise the sound and identify the fiducial points of inspiration and expiration. Viewing an estimate of the envelope of respiratory sound was described by Attenburrow (1978, 1996) for normal Thoroughbreds cantering, or galloping, during field exercise. Spectral analysis revealed that maximal expiratory energy occurred around the 200–250 Hz region. Therefore to enhance the definition of the respiratory sound envelope a finite impulse response filter of slope – 18 dB per octave filter was applied. The amplitude envelope was then normalised to 80% of the available dynamic range to prevent signal clipping after further processing. By using a peak cubic spline interpolation of the positive and negative parts of the respiratory sound envelope was produced.

Of specific interest were the use of both sound envelopes and respiratory temperature traces to determine respiratory timing parameters, including time of inspiration (Ti), time of expiration (Te) and total time for one respiratory cycle (Tt). The sample time was normalised, so that for each recording the time at which the first sample was taken was represented as time zero and the time at which the second sample was taken was represented as 15. This trend was continued for the 12 samples taken from Horses A–E and the nine samples taken from Horse F (as Horse F fatigued earlier). The three individual respiratory characteristics were plotted against normalised time, and graphs of the linear least squares trend line for Ti vs. normalised time and Te vs. normalised time for the six horses were generated. Linear regression analysis was conducted in Excel to describe the relationships between both Ti and Te for the Thoroughbred normal cases when compared to the DDSP case. The gradient of the trend line was averaged for the Thoroughbred normal horses and compared to Horse F, using a two standard deviation threshold to determine significance.
Results

A 5 second sample of the normalised tracheal sound data is shown in Figure 3a. The normalised temperature (Figure 3b) was used to determine the respiratory cycle fiducial points (i.e. the starting points of inspiration and expiration). Inspiration is the cooling, and therefore falling edge and expiration is the warming edge of the cycle. The respiratory rate may also be obtained from this chart, which for Figure 3b is 120 breaths/minute. Note that the absolute temperature was not important in the analysis presented. Figure 3c shows the spectrogram of Figure 3a. A time segment of 16 m/s was chosen in which to perform the necessary FFT (Fast Fourier transforms) which was set up to ‘bin’ the frequency components into 257 bands. The resultant 257 x 3056 spectrogram matrix may be used to statistically analyse changes in spectral energy at selected times during a respiratory cycle.

Figure 3 Thoroughbred horse at 11 m/s on a treadmill. (a) Tracheal stethoscope sound (normalised); (b) Temperature at the nares; (c) Spectrogram of the tracheal sound (from Fig. 3a).

Data quality

In an ideal recording, the spectrogram alone could potentially be used for the determination of the fiducial points, however, the tracheal signals obtained were quite noisy during intense exercise. When reviewing the noise sources in field tests, these were found to be from metal parts of the bridle, from hoof noise, from jockeys and trainers talking, and from the heart (due to the microphone being in close proximity to the carotid artery). Typical signal to noise ratios (SNRs) were of less than 12 dB for a 2 breath sample at a gallop. In treadmill tests, the added treadmill noise could result in typical SNR of less than 6 dB during intense exercise. As speed increased, the signal to noise ratio decreased (as noise increased). The fiducial points (i.e. the beginning of inspiration and expiration) were during the quietest period of the respiratory cycle. High speed exercise was required to provoke DDSP, which implied therefore that the resolution of the fiducial points would be compromised by the masking noise.
The sound envelopes for tracheal signals were calculated. Figure 4a shows a respiratory audio trace (Snd) with breath temperature (Temp); Figure 4b shows the band pass filtered audio (SndF) with the temperature (Temp). It also shows a sound envelope (SndE1), found by the cubic spline method previously described and a second envelope (SndE2) which is a low pass filtered (100 Hz @ -3 dB) version of SndE1. The regular crests labelled LF on Figure 4b are the sound of the leading footfall which during the gallop occurs at the end of inspiration. Note also the envelopes are presented in phase delayed by approximately 75 m/s.

The mesh mounted thermistor (Figure 2) was found during intense exercise to intermittently move out of the respiratory airflow. This was due to a combination of bridle movement and nare motility. The data that was successfully accumulated indicated respiratory temperature to be a very useful, low noise, low cost method of indicating the respiratory cycle. Where there was some loss of respiratory temperature data, respiratory time periods were taken just from the stethoscopy trace.

The Standardbred Horses A and B were removed from this analysis as the Standardbred gait is known to be different from that of Thoroughbreds, precluding a direct comparison. The mean values for the respiratory period variables Tt, Ti, Te, Te/Tt and Ti/Tt were found for 12 samples of 5 second data blocks spaced 15 seconds apart for the high intensity exercise period (≥10 m/s) and compared graphically. Figure 5 graphs the time period variables Tt, Ti, Te, Te/Tt and Ti/Tt during the intense exercise period for Thoroughbred Horses C, D, E and F on a treadmill (Horse F is confirmed DDSP).

For the set of 5 second data blocks, the mean variance and standard deviation were found (Table 2). Using one-way analysis of variance (ANOVA) on Tt, Ti, Te, F values were found to be much larger.
than $F_{\text{critical}}$ values (Table 2). A column plot of variance (Figure 6) graphically demonstrates that Horse F with confirmed DDSP is the significantly different group. The significant group may also be shown by applying Tukey’s post hoc test.

Table 2  Time variable statistics for Thoroughbred horses during high intensity exercise. See text for parameter definitions.

<table>
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<tr>
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<td>$F_{\text{critical}}$</td>
<td>$F$</td>
<td>$p$</td>
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<td></td>
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<tr>
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Figure 5  Graphs of the time period variables Ti, Te, Tt, Ti/Tt, Te/Tt during the intense exercise period for Thoroughbred Horses C, D, E, and F on a treadmill (Horse F is confirmed DDSP).
Figure 6  Variance of respiratory period variables Ti, Te, Tt, during intense exercise for Horses C, D, E and F. (Horse F has confirmed DDSP).

Figure 7  Graphs of the linear regression trend for time period variables Ti and Te during the intense exercise period on a treadmill for Thoroughbreds C, D, E and F (Horse F has confirmed DDSP).
To investigate whether the trends during intense exercise of the parameters Te, Ti and Tt might also differentiate normal from DDSP horses, linear regression lines were drawn and the regression gradients found (Figure 7). The gradients of Te and Ti with DDSP were significantly different from those of the normal horses C, D and E, with Te having a large difference. The gradient of Te may therefore be a highly significant indicator of DDSP.

Table 3  Linear regression gradients for Thoroughbred Horses C, D, E and F.

<table>
<thead>
<tr>
<th></th>
<th>Te gradient ((\times 10^{-3}))</th>
<th>Ti gradient ((\times 10^{-3}))</th>
<th>Tt gradient ((\times 10^{-3}))</th>
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<td>0.2</td>
</tr>
<tr>
<td>Horse E</td>
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<td>-0.2</td>
<td>0.1</td>
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<tr>
<td>Horse F</td>
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<tr>
<td>mean (Horses C, D, E)</td>
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<td>0.46</td>
<td>0.38</td>
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</table>

Figure 8 depicts the changes in amplitude of the respiratory sounds recorded during two respiratory cycles from Horse D (unaffected by DDSP) exercised at a gallop.

**Figure 8**  Graphic representation of the changes in amplitude of the respiratory sounds recorded during two respiratory cycles from Horse D exercised at a gallop.

**DDSP: A closer look**

Seven inspirations characterised by a Ti of \(>0.6\) seconds and loss of LRC rhythm were identified as associated with DDSP for Horse F (Figure 9). These episodes were also associated with the production of respiratory noise in the following expiratory period. A single DDSP deglutition event for Horse F is shown in Figure 10.
Figure 9  Ti vs. Absolute time for Horse F. The episode of DDSP is shown. Following this period, fast work ended and the recovery period began.

Figure 10  A deglutition event during a DDSP episode for Horse F.
Figure 11  During DDSP there is a deglutition followed by an attempt to recover LRC of four breaths then two further attempts to correct the displaced soft palate with the loss of LRC (Horse F).

The chart in Figure 11 demonstrates a DDSP episode for Horse F. Initially there is a deglutition (highlighted on the left side of the chart); this is followed by an attempt to recover LRC of four breaths then two further attempts to correct the displaced soft palate with the loss of LRC shown by long respiratory periods compared to the LRC period. Also, the last two attempts at deglutition are louder than the first, signifying the characteristic ‘gurgle’ distress.
Discussion

DDSP is a major diagnostic challenge due to the dynamic and transient nature of its manifestation, which occurs almost exclusively during high speed exercise.

Currently, high speed treadmill video-endoscopic recording is the only routinely used method of evaluating a horse for DDSP. This is an expensive technique and may not reach the necessary exercise intensity or allow the gait required to provoke DDSP (Geor et al. 2004; Roethlisberger-Holm 1995; Suann 2006). This implies the need for field-based diagnosis of DDSP.

Tracheal stethoscopy, nare sonography and respiratory flow have been reported (Attenburrow 1978; Geor et al. 2004) as useful in evaluating DDSP but are not routinely used. Reasons for this may include the lack of commercially available technology and software, insufficient understanding of the condition and the technical aspects of extracting meaningful information from the audio data. Further, there is a lack of data on the reliability and use of tests for routine clinical use.

Audio data for DDSP evaluation has been more commonly reported using frequency domain analysis. This study shows that analysis in the time domain has the potential to provide a simpler evaluation for the condition. It also indicates that as the condition is only observed for a Thoroughbred at high exercise intensity when there is LRC, the use of a respiratory sensor that can show changes in breathing rhythm rather than frequency components may be more appropriate. This data may be acquired using stethoscopy; however, data from a lower noise sensor is simpler with respect to applying signal processing algorithms. The pneumotach flowmeter requires the use of a mask, is expensive, and is not currently suitable for ambulatory use with a bitted bridle. Measuring respiratory temperature is a low-cost, low-noise measurement that can be made non-invasively. It offers time series data that might be automatically processed without computationally intensive signal processing that frequency domain analysis requires.

The case numbers in this study are low, and therefore population extrapolation would not be appropriate. However, the large significant differences observed in breath timing parameters as a result of DDSP suggest that the development of a time series algorithm would prove valuable in evaluation of the condition. From the standpoint of practical development of a diagnostic test that could be routinely used in clinical practice, stethoscopy is certainly useful; however, a simpler approach using a respiratory temperature sensor may provide usable data.

Simultaneous breath-by-breath measurements of tracheal sounds were measured in horses with normal URT function during field and treadmill exercise, and one horse with a confirmed DDSP.

The desired outcome was the development of new techniques to diagnose DDSP during field exercise.

Improved respiratory temperature measurement

Trial experiments have been done on an improved respiratory temperature sensor. The main requirements of this sensor are that it must have a very rapid response (<10 m/s for 5°C change), and must be able to be held within the first 15 mm of nare orifice without displacement during intense exercise.

A very thin thermocouple (0.1 mm) was used as a rugged alternative to the fragile thermistor previously used. A printed circuit board (PCB) 25 x 15 mm, supporting a surface mount thermocouple amplifier (AD597, Analog Devices) was mounted on the noseband of a Hanoverian-style bridle (Figure 12). The thermocouple sensor was made from a stiff but malleable steel wire, fixed to the PCB, and with the thermocouple wires running along its length. The sensor was covered with polyolefin heat-shrink tubing leaving the thermocouple tip (1 mm) exposed. The sensor was bent to
form a ‘Shepherd’s crook’ shape with the crook forming around the edge of the nare, and the crook’s return placing the thermocouple tip coaxial and 10–15 mm inside the nare. The trials to date show this to be a well-tolerated and reliable method for collecting respiratory temperature data.

Figure 12 Respiratory nares thermocouple mounted on a Hanoverian bridle, and coupled to a SignalScribe data logger in a pouch around the neck. During exercise, the front nose band is normally tighter than shown, preventing movement of the sensor.

Standardbred horses in this study were paced in a field. Because the Standardbred gait is different to the strictly LRC gallop observed in Thoroughbreds, it was intended that Standardbred data be treated as a statistically separate group. In this study a DDSP episode was not observed for Standardbred therefore no further comparison was considered useful.

Stethoscopy

Stethoscopy equipment is non-invasive, lightweight, compact and robust. It is quick and easy to attach to the horse prior to exercise for immediate recording. The equipment was well tolerated by horses, did not cause any noticeable behavioural changes and complied with animal welfare standards. The technique could be used during any routine exercise. Use of a flash memory MP3 recorder set for minimal compression and sampling at 22 kHz produced good quality recordings with a wide bandwidth compared with the maximum frequency of interest (5 kHz).

The positioning of the microphone on the horse was an important feature of experimental design, and was useful in helping to overcome interference from external noise, thus contributing to the success of the investigation. Previous studies have recorded respiratory sounds in front of the nares to evaluate URT disorders. At the nares, low frequency sounds generated by DDSP (Dersken 2001; Franklin et al. 2003) could be masked by sounds of similar spectral content produced from normal respiratory airflow.

In this investigation, respiratory sounds were recorded at the trachea using a contact microphone. Franklin et al. (2003) highlighted that the sound might be modified by the structures of the nasal passages and therefore not accurately represent the spectral content of sound generated by an airway obstruction. However, in this position (i.e. at the trachea) the microphone is closer to the caudal free border of the soft palate than a nare microphone and may therefore be more sensitive to DDSP. If the
resultant data is analysed in the time domain rather than the frequency domain, then the spectral content and therefore the microphone position is less critical. The nares microphone described by Franklin et al. (2003) was an acoustically insulated (externally), omnidirectional electret placed between the nares. Franklin et al. reported that with the microphone in this position, extraneous noises from the treadmill, footfall and other sources were of relatively low amplitude. Of further concern with a microphone in nare position is expiratory ‘blast noise’ when a high volume of expiratory air causes the microphone to temporarily overload. Using nare microphones and spectral analysis, respiratory sounds in the presence of induced and naturally-occurring upper airway disorders have been successfully characterised (Dersken and Robinson 2001; Franklin et al. 2003)

The respiratory sound envelope

The calculations of respiratory sound envelopes have been described in this study. The calculated envelopes are representative of those reported as estimates (Attenburrow 1978) for cantering and galloping. The expiratory phase shows the envelope’s leading edge rises faster and the trailing edge decays longer than for inspiration (e.g. Figure 8, Figure 10). Expiration is generally louder (Dersken and Robinson 2001), and although the amplitude is also a function of microphone placement, nare microphones can be affected by direct respiratory air flow pressure on expiration. During tracheal stethoscopy on a treadmill, noise was a factor in producing usable sound envelopes, as shown in Figure 4, where leading footfall is a dominant feature. Again, careful microphone placement, external acoustic insulation, and microphone directionality can reduce this effect (Franklin et al. 2003).

Deglutition

Characteristically, in response to a DDSP this study observed an attempt to maintain gait and a rapid recovery as the abnormal respiratory sound ceased, consistent with that reported by Franklin et al. (2002) and Roethlisberger-Holm (1995). Three common responses of horses upon displacement of the soft palate have been reported: (1) horses slow suddenly; (2) horses repeatedly swallow to replace the palate; and (3) horses continue to run for several seconds with the soft palate persistently displaced (Franklin et al. 2002). Periods of deglutition, as described by Attenburrow (1978), were identified in this study as being a response to DDSP and were observed in the spectogram of Horse F (Figure 11).

Deglutition has been described in normal horses (Attenburrow 1978; Manfredi et al. 2004), but is not a common phenomenon in horses with normal URT function during intense exercise. Manfredi et al. (2004) observed periods of deglutition in response to increased salivation resulting from the bit, and also reported that swallowing frequency varied widely between horses. In this study, deglutition rarely appeared in the sonograms of normal horses during exercise. From the current data it cannot be concluded that deglutition is an exclusive feature of spectograms from horses suffering from DDSP.

In Horse F, deglutition occurred at the end of inspiration and the beginning of expiration (Figure 10). These findings support those reported by Attenburrow (1978) who indicated that deglutition typically begins at the point in the respiratory cycle where expiration would normally begin. Attenburrow (1978) also reported that, at a canter, a respiratory cycle which included a period of deglutition was twice as long as an uninterrupted respiratory cycle and was thus completed in the time taken to complete two strides. On this basis, deglutition resulted in a complete cessation of inspiration and expiration for one breath and temporarily restricted a horse’s ability to breathe. It is reasonable to conclude that frequent swallowing is a cause of poor performance and is therefore not a desirable trait during athletic events.
Respiratory characteristics

There was a low variation in the Ti, Te and Tt during intense exercise for the normal horses, which is consistent with reported normal respiratory function (Dersken and Robinson 2001). For Te, the gradient of the trend line obtained for Horse F, was found to be significantly (10 standard deviations) above the mean Te gradient for unaffected horses. This suggests that the gradient of Te may be a good indicator of DDSP. A larger DDSP population would be required to determine the significance of the gradient of the Ti trend line. Further testing is required to support these findings, as only one DDSP case was analysed. These findings support those of Roethlisberger-Holm (1995) who observed a prolonged expiratory phase in horses with suspected DDSP, and these findings also confirm that clinical DDSP is a flow-limiting expiratory obstruction.

There are several possible explanations for the steeper Te trend line for the DDSP-affected animal in the observed results. DDSP affects respiratory physiology and compromises breathing, which results in the horse reaching fatigue more quickly. Durando et al. (2002) reported that regardless of breed, a similar effect on gas exchange would be seen. During DDSP all expiratory flow parameters are reduced, and gas exchange is compromised; however, there is no significant alteration of inspiratory flow (Franklin et al. 2002; Holcombe et al. 1999; Roethlisberger-Holm 1995).

Franklin et al. (2002) and Rehder et al. (1995) reported that DDSP causes a 13% reduction in minute ventilation (\(\xi_E\)) and a reduction in tidal volume (\(\xi_T\)). Alveolar gas ventilation is reduced, which decreases end-tidal oxygen (FetO2) and increases end-tidal carbon dioxide (FetCO2) and, inevitably, exacerbated arterial hypoxemia and hypercapnia during intense exercise can occur (Cotrel et al. 2006; Franklin et al. 2002; Parente et al. 2002). The impairment of gas exchange causes a decrease in oxygen consumption (Vo2) by approximately 10% (Franklin et al. 2002). The corresponding energy required to maintain exercise performance is anaerobically generated, and can account for the marked reduction in athletic activity and hastened fatigue after strenuous exercise, commonly referred to ‘choking down’. With greater anaerobic metabolism occurring at a fast gallop, an earlier onset of fatigue can be expected.

The presence of multiple abnormal dynamic URT disorders in individual horses is a common phenomenon (Durando et al. 2002; King et al. 1994; Martin et al. 2000). Horse F may have had another, concurrent, undetected respiratory problem that was potentially limiting alveolar ventilation, and consequently influencing the changes in gait and breathing. The test conditions for all horses may also not have been identical, therefore causing Horse F to have fatigued faster.

Further investigation is required to obtain results that are representative of the entire population. However, this work provides an interesting case study report, and the findings may potentially be used to develop a new approach to assess performance of racehorses and predict the onset of fatigue, whether it be due to respiratory, cardiovascular or muscular function. One of the main limitations of this study, that should be addressed in future research, was that, unlike previous studies (Franklin et al. 2002; Lane et al. 2006a; Roethlisberger-Holm 1995) horses were not exercised until fatigue, and therefore there was no reference point that was similar in all horses.

Future directions

In a study by Lafortuna et al. (1996), gait was observed throughout the locomotor cycle using a video camera and recorder mounted on a treadmill. The gait video recording was synchronised with a respiratory air flow airflow recording. A similar approach may be useful to investigate the relationship between changes in locomotion during an episode of DDSP. This could determine if the significance between the rate of change of Te during exercise for normal horses, and those suffering from DDSP, is due to a change in gait, perhaps brought about by fatigue, or some other factor. In the field this data
could be obtained by using a GPS system to measure velocity and an accelerometer to detect foot ground contact.

This research has demonstrated that time domain analysis of Thoroughbred respiration during intense exercise is a potentially useful tool in the diagnosis of DDSP. Tracheal stethoscopy is a well-tolerated, non-invasive technique that is easily used to accumulate suitable respiratory data. The methods used to analyse respiratory sound envelopes in this study were time consuming, and not yet appropriate for widespread use in the industry so further software development would be required to provide an easy-to-use test. The study also highlighted rapid respiratory temperature measurements as a low noise alternative, and demonstrated that the essential time series markers of DDSP can be observed. Data from a larger sample of DDSP cases is also required to ensure that the diagnosis is statistically valid for a general population.

Further studies are required to statistically test the reliability of simultaneous stethoscopy and thermistor recordings to quantify spectrographic differences between normal and poor-performing horses with clinical signs of DDSP. Further studies are also required to investigate respiratory features that are characteristic of DDSP and determine the statistical significance of the changes in Te during DDSP. More investigation is required to compare the differences in gait when evaluating sonography to diagnose URT disorders during high speed exercise.

A particularly interesting area for future research would be to examine horses with reported track symptoms of DDSP that have been endoscoped on a treadmill and not observed to displace the soft palate. This would require careful measurement of the exercise load, but may shed light on the provocation triggers for DDSP.

A simple field evaluation technique for DDSP would allow crossover studies to be performed on the effect of the Cornell collar\(^3\) and the tongue-tie on a DDSP horse. Further, comparison of DDSP incidence in horses ridden with bitted or bitless bridles could test the claim that bit pressure increases DDSP incidence (Cook 2003).

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\(^3\) Cornell collar is a device claimed to alleviate DDSP in horses that are so disposed.
References


Cook, W.R. (2003) Bitless bridle for governing horses and other animals. USA.


Dorsal displacement of the soft palate (DDSP) is a commonly occurring obstructive upper respiratory disease of horses. It causes a temporary respiratory airflow restriction during intense exercise resulting in loss of power and respiratory distress. It is associated with a reported gurgling sound as the horse attempts to swallow and correct the soft palate displacement.

Recording respiratory sounds from the trachea or at the nostrils has been reported as effective in the diagnosis of dorsal displacement of the soft palate. The technique is currently a research tool only and is not commercially available. This report examines tracheal stethoscopy evaluation of DDSP as a potential tool for field use in an industry wide equine setting.

This report will be of interest to veterinarians and racehorse trainers.

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